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[1.] Emil EVIN, [2.] Miroslav TOMÁŠ, [3.] Jozef VÝBOCH

BENCHMARKING OF FRICTION MODELS USED IN THE SIMULATION SOFTWARE PAMSTAMP 2G BY STRIP DRAWN TEST

[1.] DEPARTMENT OF TECHNOLOGIES AND MATERIALS, FACULTY OF MECHANICAL ENGINEERING, TECHNICAL UNIVERSITY OF KOŠICE, MÄSIARSKA 74, 040 01 KOŠICE, SLOVAKIA

ABSTRACT: *Due to nature of the actual deformation process that taking place in each individual region of deep drawing it is important to define different values of friction coefficients in different regions at FEM modelling of sheet metal stamping processes. In this contribution analytical models for determination of friction coefficients under blankholder and also on die drawing edge by strip drawing test are presented. These models were verified by experimental strip test and FEM simulation under the same contact conditions. Zn coated IF steel sheet DX45D was applied for experimental and simulation research.*
KEYWORDS: *deep drawing, strip drawn test, friction coefficient, simulation*

INTRODUCTION

Formability of steel sheets depends on material properties (mechanical properties, microgeometry of contact surfaces), geometry and also microgeometry of contact surfaces of die, blankholder pressure, applied lubricant, etc. [1,2,3,4,5].

Accurate determination of the influence of individual parameters on technological characteristics is ambiguous because single parameters are changed from one case to another and their impact on formability is changed as well. It is possible to predict the influence of material properties, geometry of die, stamping conditions on sheet formability using simulation methods which enable us to optimize the utilization of material properties under specific conditions.

With the increasing importance of the FEM analysis in preproduction, the need for exact values, which serve as input data for FEM simulation, is becoming more and more important. These input data are important for accurate description of material behaviour and contact conditions [10]. In order to predict sheet metal formability it is important to define the friction coefficient on the die contact surfaces. Friction conditions were the subject of the study [6,7,8].

To determine the friction coefficients for different combinations of surfaces and lubricants the different model (radial strip drawing friction test, pin-on-disc, etc.) and technological tests (cup test) that model the stressing of material in real stamping process have been used [5,8].

ANALYSIS OF FORCE RATIOS ON CONTACT SURFACES

Stamping processes (deep drawing, stretching and bending) can be characterized by the types of contacts between the steel sheet and the die shown in Figure 1. The most frequently occurring types of contacts during stamping are shown in Figure 1a, b. In Figure 1a the strip is sliding between two die flat contact surfaces separated by lubricant. In Figure 1b there is shown the model of bending and also sliding of strip on die drawing edge.

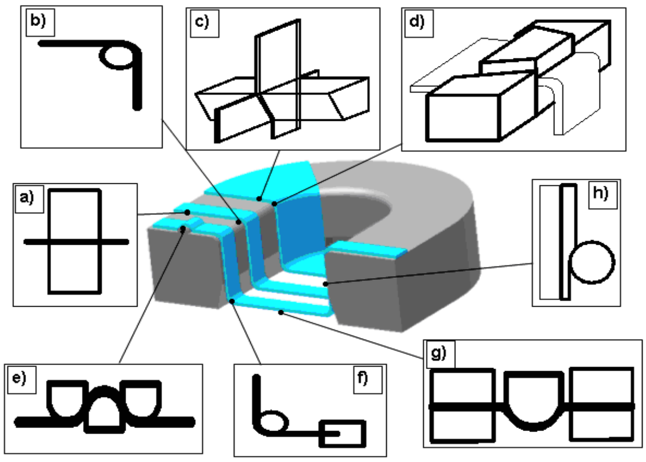


Figure 1. Types of contacts for deep drawing

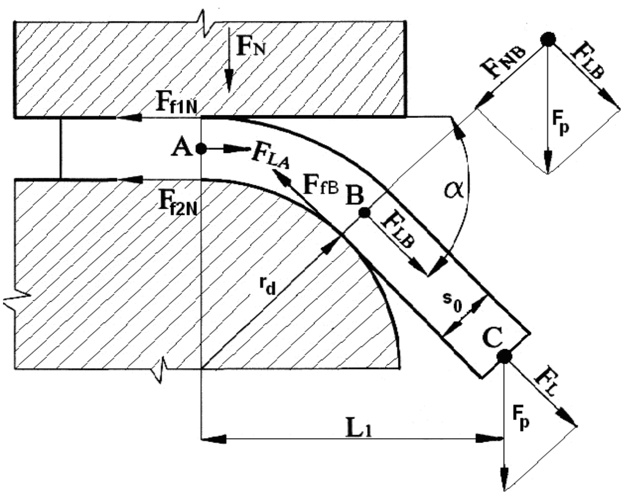


Figure 2. Scheme of forces at strip drawing.
α - wrapping angle of the die drawing edge (the bending angle of the blank around the die drawing edge)

According to these basic types of models we are able to analyze the majority of contacts for sheet metal stamping operations. To create the analytical model we proceed from the following assumptions:

- Distribution of pressure on contact surfaces is non-homogeneous.
- The contact zone between the blank and the die at drawing radius (between point A and point B, as illustrated in Figure 2) is expressed as follows: bo.rd.α, where bo is original width of blank).
- Under the same forming conditions (materials, amount of lubricant, roughness of contact surfaces, normal pressure) the friction coefficient on a flat surface is equal to that on rounded surface [4,8,9].

The most FEM codes use the Coulomb´s friction law. According to modified Coulomb´s law (state under blankholder) the friction force between the blank (sheet metal strip) and blankholder F_{f1N} is determined as follows:

$$F_{f1N} = 2.f_1.F_N \qquad (1)$$

where f_1 is the coefficient of friction between the blankholder and blank, F_N is blankholding force.

During simultaneous strip drawing under blankholder and over die drawing edge, the strip in the point A on the die drawing edge is retroactively bended – Figure 2. The back bending force F_{bA} in the point A is as follows:

$$F_{bA} = \frac{M_B}{L_1} \qquad (2)$$

and bending moment of internal forces M_B is [8,9]:

$$M_B = \frac{b_o.k_f.s_o^2}{4} \qquad (3)$$

where b_o - original width of blank, s_o - original thickness of blank, k_f - flow stress of blank (drawn strip).

Since both F_N and F_{bA} result in a reacting force at point A with the same value respectively, the friction force between the blank and the die F_{f2N} is as follows [4,9]:

$$F_{f2N} = (F_N + F_{bA}).f_2 \qquad (4)$$

and summary friction force F_{fA} at point A is:

$$F_{fA} = F_N.f_1 + (F_N + F_{bA}).f_2 \qquad (5)$$

where F_{f1N} and F_{f2N} are friction forces between flat dies, f_1 and f_2 - friction coefficients between flat dies.

If we assume that friction coefficients in zone under blankholder (between blank and blankholder f_1 and between blank and die f_2) are equal ($f_1 = f_2$), then the friction coefficient may be expressed as follows [4,9]:

$$f_{1,2} = \frac{f_1 + f_2}{2} \qquad (6)$$

and total friction force F_{fA} in the point A will be:

$$F_{fA} = 2.f_{1,2}.F_N + F_{bA}.f_{1,2} \qquad (7)$$

According to calculation of rope friction the longitudinal drawing force F_L at point A is [8,9]:

$$F_{LA} = F_{fA}.\exp(\alpha.f_3) \qquad (8)$$

where f_3 – friction coefficient on the die drawing edge.

Contact length L_{cr} between blank and die drawing radius r_d can be expressed as follows:

$$L_{cr} = r_d.\alpha \qquad (9)$$

where α is the bending angle of the blank around the die drawing edge, r_d - radius of die drawing edge, b_b - contact width of grip and blank (strip), L_b - contact length of grip and blank (strip).

If we assume α = π/2 then longitudinal drawing force F_L will be:

$$F_L = [(2.F_N + F_{bA}).f_{1,2}].e^{\frac{\pi.f_3}{2}} \qquad (10)$$

then $F_p = F_L$ (11)

If we suppose that in the case of simulator with rotating roller the friction coefficient on the drawing edge is f_3 = 0, then the drawing force F_p after establishing into Eq. (11) and after arrangement will be:

$$F_{p(f3=0)} = (2f_{1,2}.F_N + F_{bA}.f_{1,2}) \qquad (12)$$

If we express from Eq. (12) the friction coefficient in conformity with the Coulumb´s law as portion of difference of drawing $\Delta F_{p1,2}$ (f_3=0) to difference of blankholding forces $\Delta F_{N1,2}$ due to the reference blankholding force $F_{N1,ref}$ = 2 kN we obtain the following equation:

$$f_{1,2} = \frac{F_{p2(f3=0)} - F_{p1,ref(f3=0)}}{2(F_{N2} - F_{N1,ref})} = \frac{\Delta F_{p1,2(f3=0)}}{2.\Delta F_{N1,2}} \qquad (13)$$

where F_{bA} is bending force, $F_{N1,ref}$ = 2kN, F_{N2} blankholding force whereas it is valid $F_{N1,ref} < F_{N2}$, $F_{p2(f3=0)}$ drawing force generated by blankholding force F_{N2}, $F_{p1,ref(f3=0)}$ drawing force generated by blankholding force $F_{N1,ref}$.

Stress acting on the contact areas under the blankholder and on drawing edge of die (see Figure 1b) was modelled by simulator in horizontal position and with fixed roller - Figure 3. Assuming that the roller is fixed, the friction coefficient on the drawing edge is f_3 >0, then we can calculate the drawing force by the Oehler´s formula:

$$F_{p(f3>0)} = F_{bA} + (2f_{1,2}.F_N + F_{bA}.f_{1,2}).\exp(\alpha.\pi/2) \qquad (14)$$

and

$$F_{p(f3=0)} = F_{bA} + (2f_{1,2}.F_N + F_{bA}.f_{1,2}) \qquad (15)$$

Then after arrangement we obtain:

$$F_{p(f3>0)} = F_{p(f3=0)}.[\exp(\pi.f_3/2)] \qquad (16)$$

If the wrapping angle is α = 90° (in radian π/2), then the friction coefficient f_3 on die drawing edge is:

$$f_3 = \ln\left(\frac{F_{p(f3>0)}}{F_{p(f3=0)}}\right)\frac{2}{\pi} \qquad (17)$$

where $Ft_{(f3=0)}$ is drawing force generated by a rotating roller, $Ft_{(f3>0)}$ is drawing force generated by a fixed roller, f_3 is friction coefficient on the die drawing edge.

FEM SIMULATION OF STRIP DRAWN TEST

Strip drawing simulation was realized using software Pam-Stamp2G. Model of experimental device was created in 3D CAD/CAM software Pro/Engineer and its components were exported in neutral format igs. The die geometry was created according to real testing device: drawing die radius 10 mm, flat die part dimensions 30 in length and 50 mm in width (area of blankholder). Meshing of die components and strip were realized in meshing module of Pam-Stamp 2G during models import. Meshed die components are shown in Figure 3. Drawing die was split as it is shown in Figure 1 on two parts in order to simulate different friction conditions under blankholder and drawing radius.

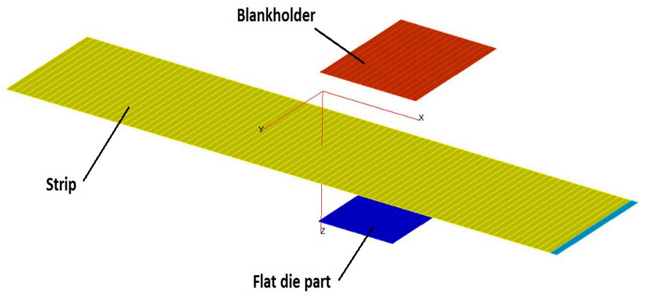


Figure 3. Set-up of strip drawing simulation – strip pulling

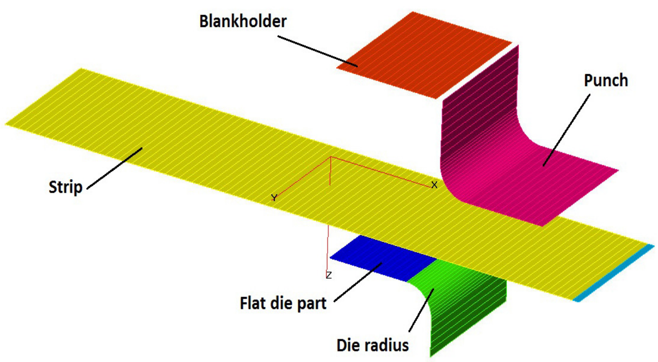


Figure 4. Set-up of strip drawing simulation - strip bending and pulling

There were researched two states of strip drawing as it is shown in Figure 3 and Figure 4: strip drawing with blankholding (where strip was moved in direction x – see Figure 3) at first, and strip drawing with bending and pulling (where strip is bent and then pulled in direction z – see Figure 4) at second.

During simulation states strip was pulled with velocity 1 m/s applied in corresponding axis. Section force was defined between strip end nodes during simulation and section force element and strip drawing force was then calculated. Blankhoding force in z-direction and "Accurate" contact type were applied during both simulation stages.

Experimental material DX54D was verified in simulation and Holomon's hardening curve was defined according to measured data shown in Tab. 1. As a yield law Orthotropic Hill48 material law was used with Isotropic hardening definition. Orthothrophic type of material anisotropy was defined by Lankford's coefficients according to measured data shown in Tab. 1. Thickness of material was 0.78 mm.

Table 1. Material properties of DX57 D – zinc coated IF steel sheet

Rolling direction	0°	45°	90°	Average values
Yield strength 0,2% YS [MPa]	170	180	184	182
Ultimate tensile strength UTS [MPa]	292	304	297	300
Material constant K [MPa]	492	503	487	497
Strain hardening exponent n	0,208	0,203	0,215	0,207
Lanksford's coefficients r_0, r_{45}, r_{90}	1,98	1,04	1,59	1,59

In order to compare experimental results of strip drawing and simulation were set up blankolding force 4 kN with friction coefficients 0,125 (blankholder) and 0,08 (die radius) and blankolding force 9 kN with friction coefficients 0,110 (blankholder) and 0,07 (die radius). These values were chosen based on experimental results of strip drawn test using testing device in Figure 5.

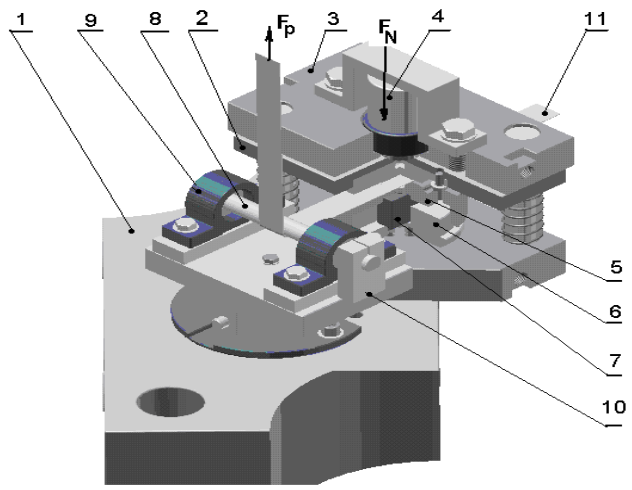


Figure 5. Model of friction simulator – strip drawing test. 1-base plate, 2-middle plate, 3-upper plate, 4-hydraulic clamping cylinder, 5-upper grip, 6-lower grip, 7- dynamometer for measurement of blankholding force, 8-roller, 9-ball bearings, 10- brake mechanism of the roller, 11-strip

EXPERIMENTAL SIMULATION OF STRIP DRAWN TEST

For modelling of stress state on flat and curved regions was used the friction simulator, shown in Figure 6. This simulator enables the modelling load of contact surfaces under blankholder modelled by using a simulator with a rotating roller is shown in Figure 1a.

Load of contact areas on the die drawing edge with a fixed roller is shown in Figure 1a,b.

Drawing conditions were as follows: blankholding forces FN = 4.0, 9.0 kN, strip drawing speed v = 10 mm/s, roughness of the upper and lower grips Ra = 0.4 μm, roughness of roller Ra = 0.4 μm. The surface of steel strip was lubricated with lubricant Anticorit Prelube 3802-39 S with a kinematic viscosity of 60 mm2/s at 40 °C in the amount of 2 g/m2.

Table 2 and Table 3 shows adjusted values of blankholding forces F_N and friction coefficients for simulation, measured drawing forces F_{f1N}, $F_{p(f3=0)}$ and $F_{p(f3>0)}$. For evaluation of friction coefficient in the area under blankholder were applied analytical Eq.(1) and Eq. (13). The Eq.(17) for calculation of friction coefficient f_3 on drawing edge of stamping die was used.

Table 2. Calculated friction coefficients – strip drawing without bending (Figure 3)

Material DX 54 D	Blankholding force F_N [N]	Drawing forces [N]	Friction coefficients	
		State 1 F_{f1N} [N]	$f_{1,2}$ according to relation (1)	$f_{1,2}$ according to relation (13)
FEM simulation, $f_{initial}$ = 0,125	4000	999	0,125	-
	9000	2254	0,125	0,125
FEM simulation, $f_{initial}$ = 0,11	4000	878	0,11	-
	9000	1981	0,11	0,11
Experiment	4000	998	0,125	
	9000	1986	0,11	0.099
FEM simulation and Experiment conformity [%]	4000	100,1	100	-
	9000	99,7	100	90-100

Note: State 1 – strip pulling within flat surfaces of blankholder and die

Table 3. Calculated friction coefficients – strip drawing with bending (Figure 4)

Material DX 54 D	Blankholding Force F_N [N]	Drawing forces [N]		Friction coefficients		
		State 2 Fp $_{(f3=0)}$ [N]	State 3 Fp $_{(f3>0)}$ [N]	$f_{1,2}$ acc. to rel. (13)	$f_{1,2}$ acc. to rel. (1)	f_3 acc. to rel.(17)
FEM simulation, $f_{initial}$ = 0,125	4000	1362	1546		0,17	0,08
	9000	2631	-	0,127	0,146	
FEM simulation, $f_{initial}$ = 0,11	4000	1246	-		0,156	
	9000	2365	2619	0,117	0,131	0,065
Experiment	4000	1108	1258		0,125	0,08
	9000	2361	2646	0,099	0,11	0,07
FEM simulation and xperiment conformity [%]	4000	120	123	-	136	100
	9000	100	99	100 - 106	119	93

Note: State 2 – strip pulling and bending along rotating cylinder; State 3 – strip pulling and bending along fixed cylinder

REACHED RESULTS AND DISCUSSION

Results of strip drawing simulation are shown in Figure 6. There is shown strip bending force is independent on both blankholding force and friction conditions and its maximal value is 0,439 kN. Average value of strip pulling force is 1,546 kN; 2,619 kN respectively. A moving average filter (MVA) in PamStamp 2G with a window width of 25 is applied on these curves and the average value of strip pulling force is calculated as average value from time 60 s till the end of simulation.

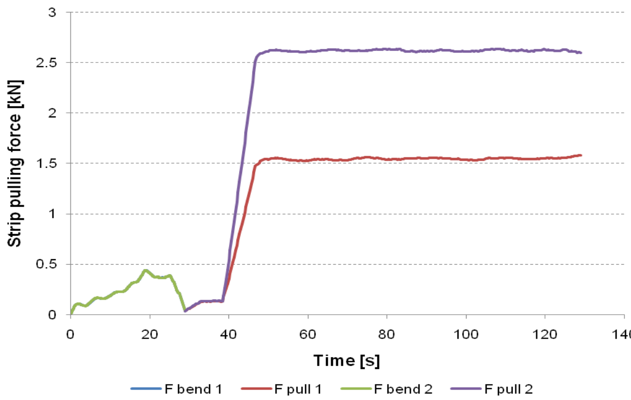
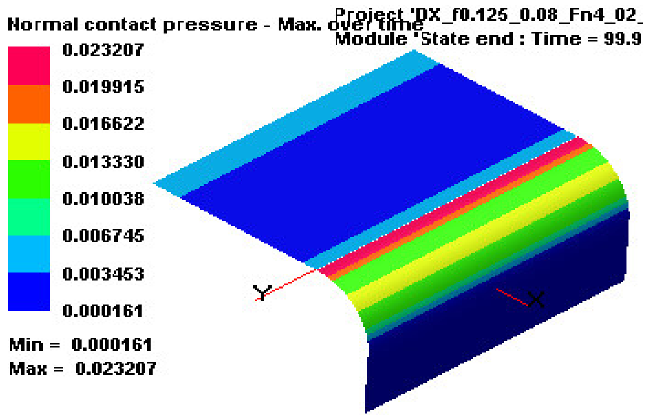
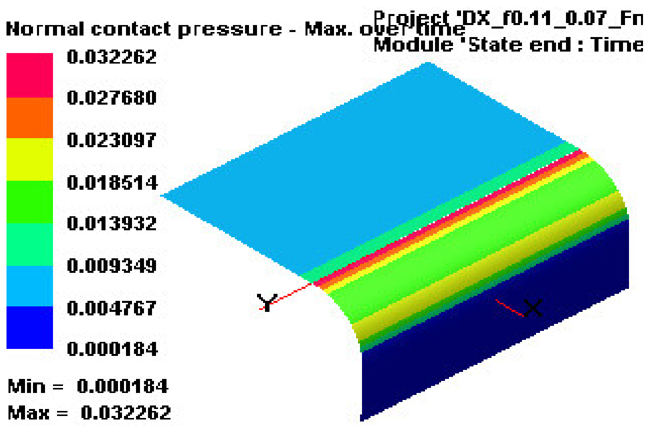


Figure 6. Graphs showing strip bending and pulling force at different friction and holding conditions.
a) F_N = 4 kN; $f_{1,2}$ = 0,125; f_3 = 0,08
b) F_N = 9 kN; $f_{1,2}$ = 0,11; f_3 = 0,07



a) F_N = 4 kN; $f_{1,2}$ = 0,125; f_3 = 0,08;



b) F_N = 9 kN; $f_{1,2}$ = 0,11; f_3 = 0,07

Figure 7. Maximal normal contact pressure during strip drawing simulation

Figure 7 shows normal contact pressure during strip drawing simulation. Maximal values of normal contact pressure are 23,207 MPa; 32,262 MPa respectively and they are on the first part of die radius in both cases. Course of normal contact pressure along flat die part and die radius is shown on Figure 8. As it is shown in figure, there are two maximum values of normal contact pressure. The first one is located at the radius start with maximum values of normal contact pressure 23,207 MPa and 32,262 MPa. The second one maximum is at blankholding force 4 kN in 50,625° with value of 14,275 MPa and at blankholding force 9 kN in 61,875° with value of 20,394 MPa.

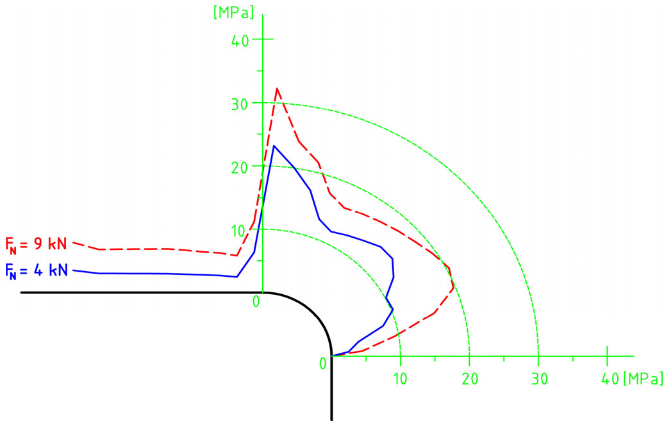


Figure 8. Course of normal contact pressure along flat die part and die radius

Conclusions / Summary

Based on reached results of strip drawing experiments and FEM simulation it is possibly to state:

1. *With pressure increasing on contact surfaces between blank and die, using Anticorit lubricant, friction coefficient values decrease. Concern Fuchs declares the same tendency in its commercial papers. We assume Anticorit lubricant includes high-pressure additives and its efficiency increases with pressure rising.*
2. *Evaluation of friction coefficients from strip drawing test between flat die parts and strip drawing test with strip bending along fixed and rotating cylinder according to eq. (1) gave greater differences (up 39 %) than evaluation of friction coefficients according to eq. (13), with difference approx. 6 %.*
3. *Better conformity was reached between friction coefficients computed from strip pulling force values according to eq. (13) than according to eq. (1) taking into account friction coefficients computed from experimentally measured pulling and blankholding forces. The advantage of eq. (13) is that friction coefficient is computed from ratio of pulling and blankholding force differences, what eliminates the influence of some factors (bending force influence, friction in bearings etc.) to pulling force.*

By comparing friction coefficients on die radius computed according to eq. (17) from experimental measured and FEM simulation results were reached difference approx. 7 %. It means friction model described by eq. (17) for drawing die radius implemented in PAM STAMP 2G simulation software is in very good conformity to experimental measured results.

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